Renovation of Buildings using Steel Technologies (ROBUST)

RFCS Project RFSR-CT-2007-0043

WP 5.1
Development of an Economic Justification Software Tool for Renovation in Steel

Date: 2010
Author: Guillaume Vannier

SCI, Silwood Park, Ascot,
Berkshire, UK, SL5 7QN
Tel: + 44(0) 1344 636525
Fax: + 44(0) 1344 636570

Development of an Economic Justification Software Tool for Renovation in Steel

1 Introduction

In this WP, a multi-criteria tool was developed to support developers' decisions regarding whether to demolish or renovate a building. The tool will estimate the potential cost savings arising from over-cladding and/or over-roofing and/or constructing a roof-top extension using steel technologies. It will include issues such as savings in heating bills, reduced maintenance costs, improved visual aspects, increased rental value and the benefit of a longer building life. National variations in certain parameters will be taken into account.

2 Review of existing tools

To start with, the four following software tools which deal with the economic assessment of renovating buildings (albeit to varying extents) were investigated:

- ENVEST (from the Building Research Establishment)
- Retrofit Adviser (EMPA) (currently under development)
- Carbon calculator Pre-design tool (Faithful & Gould)
- VTT LCC software

The functionality of these tools was compared against the following criteria:

1. Does it specifically cover building renovation?
2. Does it include over-cladding?
3. Does it include over-roofing?
4. Does it include roof-top extensions?
5. How is the energy use before and after renovation calculated? Does it take into account occupancy, solar gain, percentage openings etc?
6. Does it use a net present value or return investment economic model?
7. How many climates are considered?
8. Does it include a carbon index applied to energy use
9. Does it include social aspects?
10. What assumptions are made about the inclusion of balconies in the building envelope?

None of the tools reviewed specifically dealt with the economic justification of steel renovation systems. However, the evaluation exercise was useful as it showed various options for interface design for input and output.

3 Functional specification and prototype overview

The tool covers rectangular, multi-storey residential and commercial buildings and single storey industrial buildings. It is a pre-design tool to facilitate the decision making process on whether to renovate a building, while enabling the relevant parties involved in the decision making to compare the economic viability of the following steel intensive renovation solutions:

- Over-cladding
- Over-roofing
- Roof-top extension
- Over-cladding and over-roofing

- Over-cladding and roof-top extension

The main result provided by the tool for the assessment of the economic viability of renovating a building using the above renovation solutions is the payback period. To calculate it, the most difficult issue is the determination of the energy savings following renovation. Several full building thermal simulation software tools are available on the market for assessing the energy performance of buildings but these require users to possess a high level of expertise in both building physics and in the use of the software. However, the objective of this piece of work is to develop a standalone tool able to provide an estimate of the energy savings without needing to rely on thermal simulations carried out by experts. In reality, the energy savings depend on a wide range of parameters specific to a given building but providing an approximate estimate of the energy savings will be useful for users to assess the impact of various measures on energy efficiency. Within the tool, two methods will therefore be available to the user for the calculation of the energy savings:

- A simplified method whereby the energy savings will be estimated by the tool itself based on empirical relationships and
- A direct input method whereby the user will be able to input the results from a more detailed energy calculation with a third party thermal simulation software.

Several parametric studies using full building thermal simulation software tools have been carried out for the derivation of the empirical relationships to be used in the simplified method for estimating the energy savings after renovation. The parameters varied in these parametric studies are those which affect the energy performance of buildings most strongly such as the building dimensions, U-values, percentage glazing, orientation, air-tightness, etc.

The economic model takes into account the net present value of the following parameters (where relevant) for the calculation of the payback period:

- Cost savings arising from energy savings after renovation:
  The energy demands of the building before and after renovation will be estimated using one of the two methods described above so as to estimate the energy savings. A database of energy costs for several sources of energy has been developed for several European countries in order to convert the energy savings into cost savings.
- Savings due to reduced maintenance:
  Maintenance costs due to repair of the existing facades and roofs is expected to increase over time in the absence of over-cladding. Over-cladding therefore leads to a decrease of the maintenance costs due to arrested deterioration.
- Increased rental income following renovation:
  Rental charges are expected to be increased following renovation due to the higher quality environment. In order to estimate the increased rental income, a simple database of rental charges for commercial, residential and industrial buildings has been developed for several European countries.
- Additional income due to additional space:
  Over-cladding work is often combined with the creation of new floor level(s) by a roof-top extension. This creates additional rental income with the rental charges for these new built spaces being generally higher than those of the original parts of the building. A simple database of rental charges for roof-top extensions has been developed for several European countries for estimating the income generated by the rent of such additional spaces.
- Construction costs:
  A simple database of construction costs for over-cladding, over-roofing and roof-top extensions has been developed for residential, commercial and industrial buildings and for several European countries.
- Cost of borrowing to pay for the renovation work:
  The amount of interest paid when financing the renovation work with a loan is taken into account in the calculation.

A detailed functional specification has been developed for the software tool whereby the required user inputs as well as outputs have been defined and broken down into the following logical sections for the development of a user-friendly graphical interface:

- Homepage:
  This section will provide a description of the tool and its objectives and will enable users to assign a name to the renovation project to be assessed.
- Input of properties of original building:
  This section will enable users to provide the physical and thermal properties of the original building to be used for the calculation of the payback period and the energy savings.
- Input of properties of renovated building:
  This section will enable users either to provide the thermal properties of the building before and after renovation, or to provide directly the energy demands of the building before and after renovation as calculated by a third party software. These inputs will be used for estimating the energy savings.
- Results:
  This section will provide the user with the payback period together with the breakdown of the various costs related to the payback period for al the renovation solutions taken into account in the tool. The interface design will emphasise the most important results to the user.
- Default values:
  This section will enable users to modify the default values used by the tool for the calculation of the payback period in order to refine the results. These default values depend for instance on the country in which the building is located as well as its type (residential, commercial or industrial).
- Help and assumptions
  This section will comprise a simple user guide and provide the user with the main assumptions and limitations of the tool.

4 Parametric studies to derive empirical relationships for estimating building energy demands

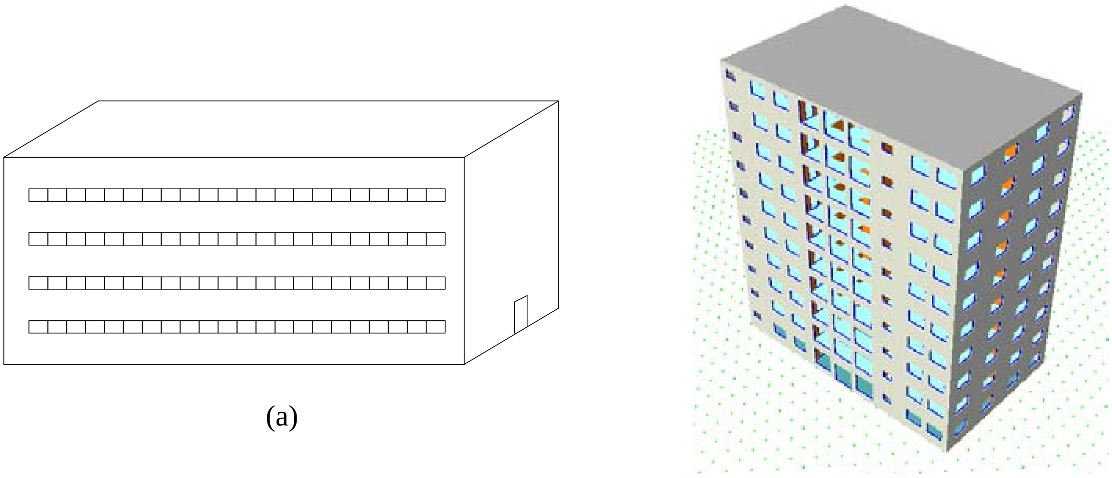
Parametric studies using full building thermal simulation software tools have been carried out in order to derive empirical relationships between the key parameters affecting the energy performance of buildings. These studies have been conducted for three reference buildings.

4.1 Office and residential building

The four storey office building and ten storey residential reference buildings are shown in Figure 4.1.

The effect of the following parameters on energy performance was identified for both commercial and residential buildings:

- Building location (climate)
- Building dimensions (shape and height)
- Building orientation
- Percentage glazing
- U-values (U-values of façade and roof varied separately)
- Air-tightness
- Addition of a roof-top extension



(a)

(b)

Figure 4.1 *(a) Office reference building and (b) residential reference building for parametric studies*

The energy demand of a building is a multidimensional function of its components (described by parameters x_i), the climate and the building use. The energy demand $Q_{p,orig}$ of a building before renovation (original state) can be expressed as follows:

$$Q_{p,orig} = f(x_{1,orig}, ..., x_{n,orig}, \text{climate}, \text{use})$$

Similarly, the energy demand $Q_{p,retro}$ of the same building after renovation (retrofitted state) can be expressed as follows:

$$Q_{p,retro} = f(x_{1,retro}, ..., x_{n,retro}, \text{climate}, \text{use})$$

In order to define the function *f*, it is proposed, as a starting point, to assess the sensitivity or effectiveness of the various parameters x_i using partial derivatives (as follows) from which a simplified calculation method will be developed for the estimating the energy demand of the building before and after renovation.

$$\text{Effectiveness}(x_i) = \frac{\partial}{\partial x_i}(Q_{p,retro})$$

The parametric studies for both residential and commercial buildings have provided numerous useful results showing the effect of the considered parameters on the energy performance of the buildings. The following figures provide a sample of the results obtained.

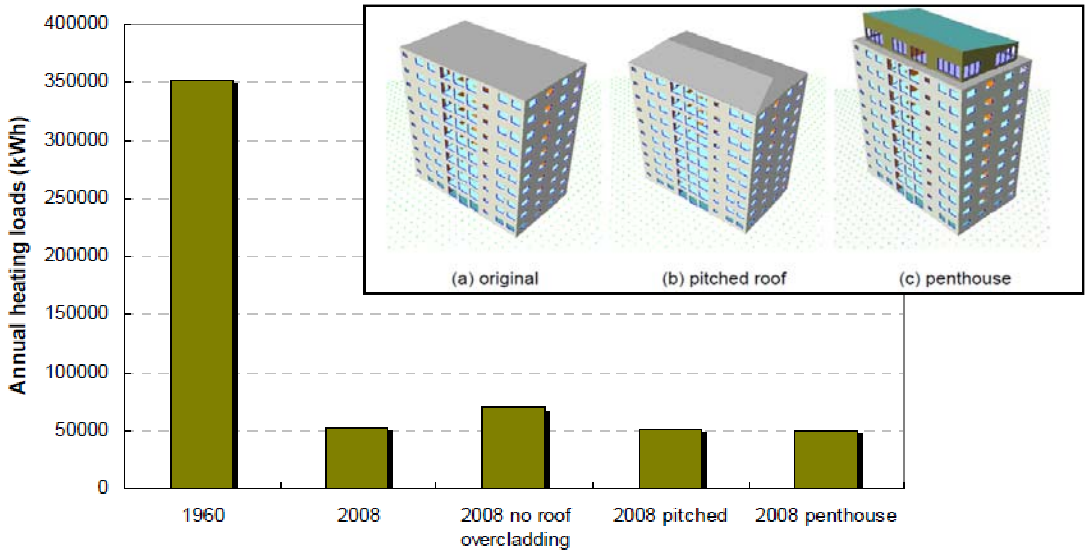


Figure 4.2 *Annual heating loads for various configurations of a residential building*

Figure 4.2 shows the annual heating load for several configurations of a residential building including the reference building (labelled as from 1960) as well as the building in various renovated states namely entirely over-clad (2008), with over-cladding on the façade only, with over-cladding on the façade and a pitched roof and with over-cladding on the façade with a roof-top extension. This graph shows that significant energy savings can be made using renovation.

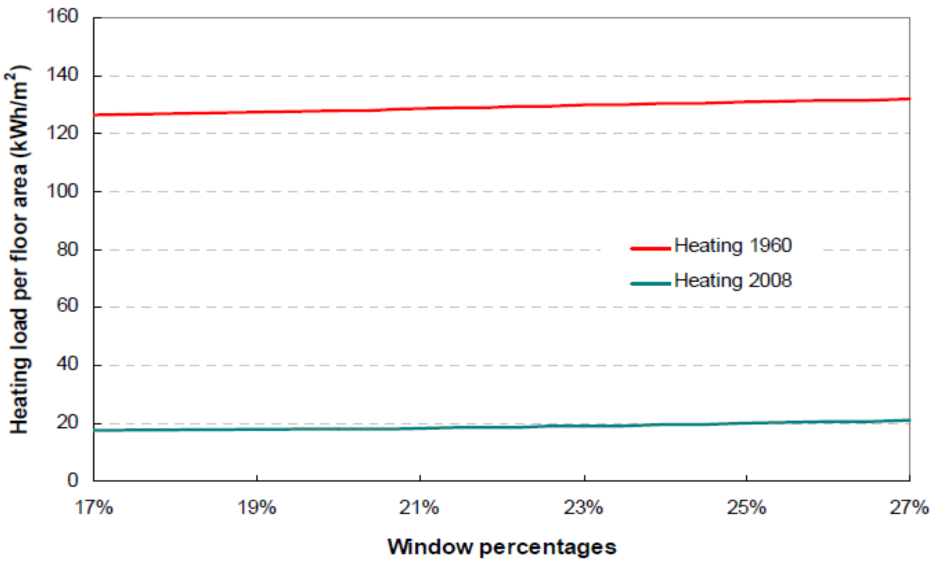


Figure 4.3 *Variation of the annual heating load per floor area with the percentage glazing*

Figure 4.3 shows the linear variation of the heating load per floor area with the percentage glazing for the reference residential building (1960) and for the building in its renovated state (2008). This result will be useful for defining a relationship between the building energy demand and the percentage glazing as the buildings considered for renovation by users will have different percentage glazing. Such relationship will then be incorporated into a simple calculation method to all residential buildings.

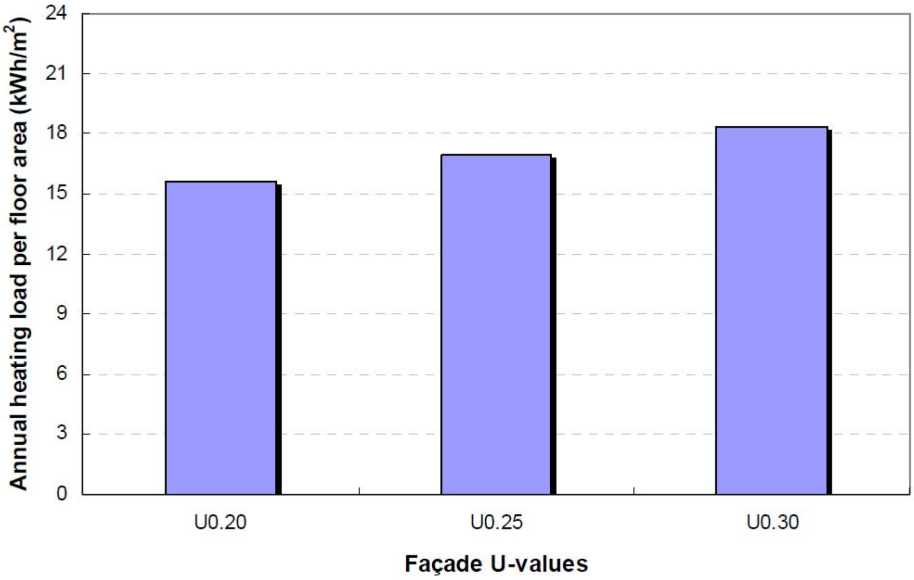


Figure 4.4 *Variation of the annual heating load per floor area with the facade U-value*

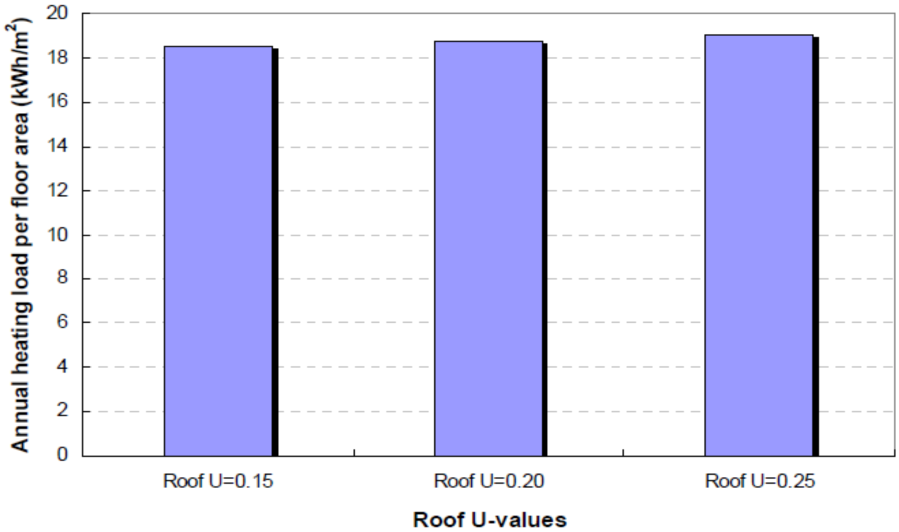


Figure 4.5 *Variation of the annual heating load per floor area with the roof U-value*

Figure 4.4 and Figure 4.5 show the variation of the annual heating load per floor area of the reference residential building with the façade U-value and roof U-value respectively. These results will be used for defining relationships between the building energy demand and the U-values of the façade and roof to be incorporated into a simple calculation method applicable to all residential buildings.

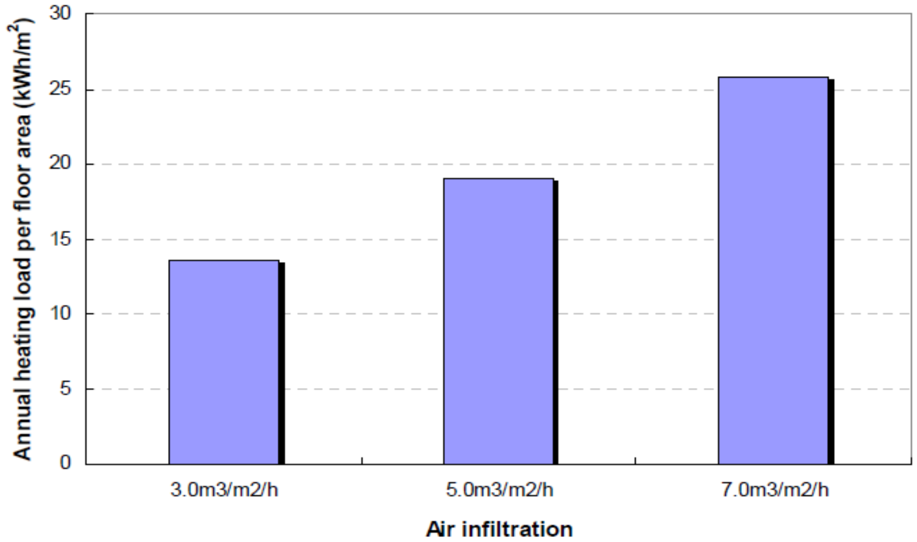


Figure 4.6 *Variation of the annual heating load per floor area with the air-tightness*

The significance of the air-tightness of the building on its energy performance is shown in Figure 4.6. This will be used, as for the other parameters, to derive a relationship between the air-tightness and the building energy demand to be incorporated into a simple calculation method applicable to all residential buildings.

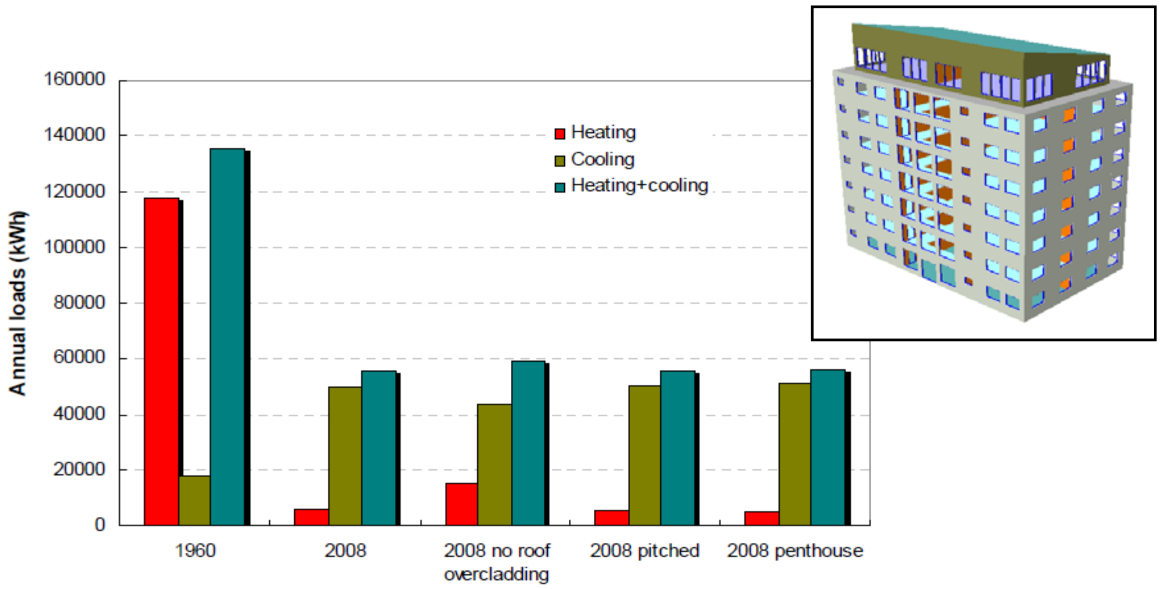


Figure 4.7 *Annual heating and cooling loads for various configurations of commercial buildings*

Figure 4.7 shows the annual heating and cooling loads for several configurations of a commercial building including the reference building (labelled as from 1960) as well as the building in various renovated states namely entirely over-clad (2008), with over-cladding on the façade only, with over-cladding on the façade and a pitched roof and with over-cladding on the façade with a roof-top extension. This graph shows that significant energy savings can be made using renovation, however, the cooling energy demand of a building compliant with current energy performance standards (typically built in 2008) is actually higher than that of an old building (typically built in 1960).

The original scope of the tool was limited to the estimation of the heating energy demands. However, the above results showed that it is not possible to ignore the effect of renovation on the cooling energy demand of commercial office buildings, as it increases with the performance of the thermal envelope and as this would lead to an unacceptable overestimation of the energy savings.

By improving the performance of the thermal envelope of a building, the renovated building is able to retain more heat and is therefore more susceptible to overheating during the summer period. The cooling energy demand therefore increases in order to regulate the increased indoor temperatures during the summer. Additional simulations were therefore carried out for commercial office buildings to provide more data on the effect of renovation on the cooling energy demands with a view to derive empirical relationships which make allowance for the cooling demand.

For both residential and commercial buildings, the empirical relationships between the key parameters affecting the building energy performance and the energy demands were incorporated into a simple calculation method applicable to all buildings.

The detailed report of the parametric study for office buildings is available in a WP1 activity report from RWTH and for the residential building is available in a WP5 activity report from Oxford Brookes University (sub-contractor to SCI).

4.2 Industrial building

The model of the industrial building used in these thermal simulations is shown in Figure 4.8 below.

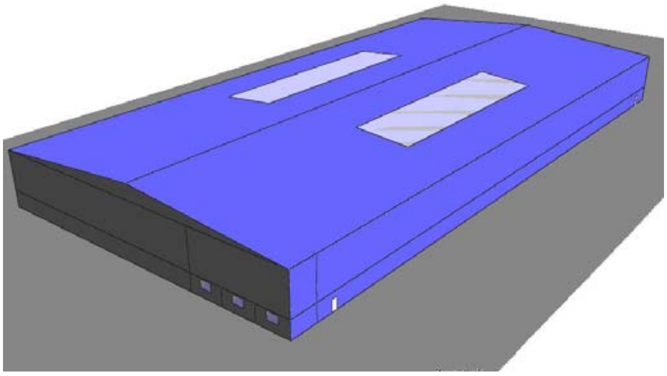


Figure 4.8 *Model of industrial building used in thermal simulations*

A total of 90 simulations were carried out and within those, the following parameters were varied:

- Building location (climate)
- Building dimensions (two sizes were looked at respectively 30*60*6m and 60*120*10m)
- Building orientation
- Percentage of roof-lights
- U-values (U-values of façade and roof)
- Air-tightness

The detailed report of the parametric study for industrial buildings is available in a WP2 activity report from Corus.

5 Derivation of empirical relationships for estimating building energy demands

Empirical relationships for estimation of the energy demands have been developed which are based on the parameters that were varied in the full thermal analyses described in the previous section. These parameters were defined according to the required user inputs and were carefully selected so as to be at the adequate level of detail for the type of users and design stage considered within the scope of the tool. These basic parameters are as follows:

- Building dimensions (length, width, height, no of storeys, roof slope)
- Percentage openings of total façade area / Percentage roof-lights of total roof area
- U-values of walls, roof, windows / roof-lights
- Air-tightness

In the original scope of the tool, it was planned to include the effect of building orientation on the energy demands. However, as the scope of the tool is limited to buildings with the same percentage of openings on all sides, the simulation results showed that the effect of orientation on the energy demands of such buildings was insignificant. The effect of orientation is therefore not included in the tool.

As a first attempt, the heat loss calculations as shown in expression (1) below was used for the estimation of the heating energy demands (which corresponds to the total energy demands in the case of the residential and industrial buildings):

$$Heating\ Demand\ (kWh) = \sum_{i=01:00am,1st\ Jan}^{i=12.00\ pm,31st\ Dec}(T_{ref_i} - T_{ext_i}) \times \left(\frac{U_{wall}A_{wall} + U_{roof}A_{roof} + U_{window}A_{window}}{1000} + \frac{ACH \times V_{Building}C_{p_{air}}\rho_{air}}{3600}\right) \quad (1)$$

where:

T denotes a temperature (K)

U denotes a U-value ($Wm^{-2}K^{-1}$)

A denotes an area (m^2)

ACH denotes the air change per hour (hr^{-1})

V denotes a volume (m^3)

$C_{p\ air}$ denotes the specific heat of air ($kJkg^{-1}K^{-1}$)

ρ_{air} denotes the density of air (kgm^{-3})

As compared to the results from the full thermal analyses, the above heat loss calculation led to significant differences in terms of the calculation of the energy demands and savings (+/- 20%) and this solution was therefore discarded. However, the basic format of the heat loss calculation was retained for the definition of the empirical relationships as it identifies the contribution of the following elements to the total heating energy demand:

- Climate, via the difference between internal and external temperatures
- Heat loss through walls
- Heat loss through the roof
- Heat loss through the windows / roof-lights
- Heat loss via air-infiltration

The heat loss calculation has therefore been modified into the following generic expression for the calculation of the heating energy demands:

$$Heating\ Demand\ (kWh) = \Delta T_k \times \left(f_1(U_{wall}A_{wall}) + f_2(U_{roof}A_{roof}) + f_3(U_{window}A_{window}) + f_4(ACH \times V_{Building})\right) \quad (2)$$

where $$\Delta T_k = \sum_{i=01:00\,am,1st\,Jan}^{i=12.00\,pm,31st\,Dec} (T_{ref_i} - T_{ext_i})$$

$$f_1, f_2, f_3, f_4 \text{ are quadratic functions of the form } f(x) = ax^2 + bx + c$$

The above generic expression is valid for the empirical relationships defined for all the three building types, however ΔT_k, f_1, f_2, f_3 and f_4 are different for commercial, residential and industrial buildings.

In expression (2), the term ΔT_k is the sum of the hourly difference between the internal temperature and a reference temperature. The hourly external temperature T_{ext} was defined according to meteorological data and the reference temperature T_{ref} is equal to the inside temperature minus a constant (the inside temperature was defined according to the heating profile used in the relevant full thermal analyses). This constant was chosen so that the difference between the heating demand as calculated according to expression (2) and that obtained form the full thermal simulations was minimal (via the computing of f_1, f_2, f_3 and f_4). The subscript k of ΔT_k differentiates ΔT for the various climates considered as it will not have the same values for the London, Berlin and Helsinki climates, due to the different external temperatures. However, the constant used to calculate T_{ref} from the internal temperature is the same, irrespective of the climate considered.

The variables of the quadratic functions f_1, f_2, f_3 and f_4 namely $U_{wall}A_{wall}$, $U_{roof}A_{roof}$, $U_{window}A_{window}$ and $ACH*V_{building}$ have been normalised so as to be able to describe any building size or shape (by considering areas and volumes). These variables respectively characterise the heat loss through the walls, roof and windows as well as the heat loss via air-infiltration.

The difference between the heating energy demand as calculated via the empirical relationships defined according to expression (2) and the heating energy demand as calculated via the full thermal analyses carried out for residential and industrial buildings are considered to be within an acceptable range (+/- 9%) for the purpose of the economic justification software tool.

6 Implementation of software tool

The software tool was implemented into a spreadsheet using Microsoft Excel. The following figures show screenshots of the tool.

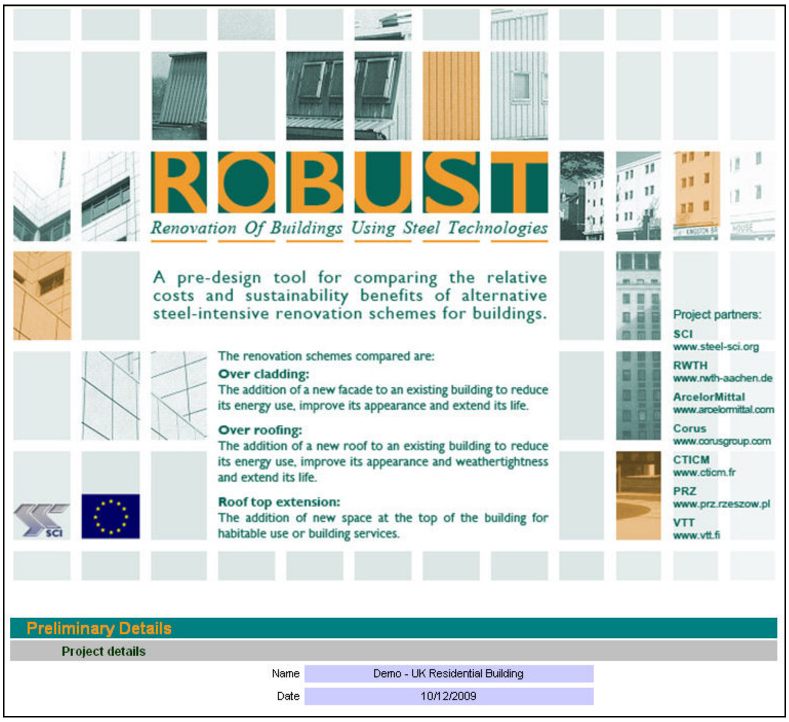


Figure 6.1 *Screenshot of software tool homepage*

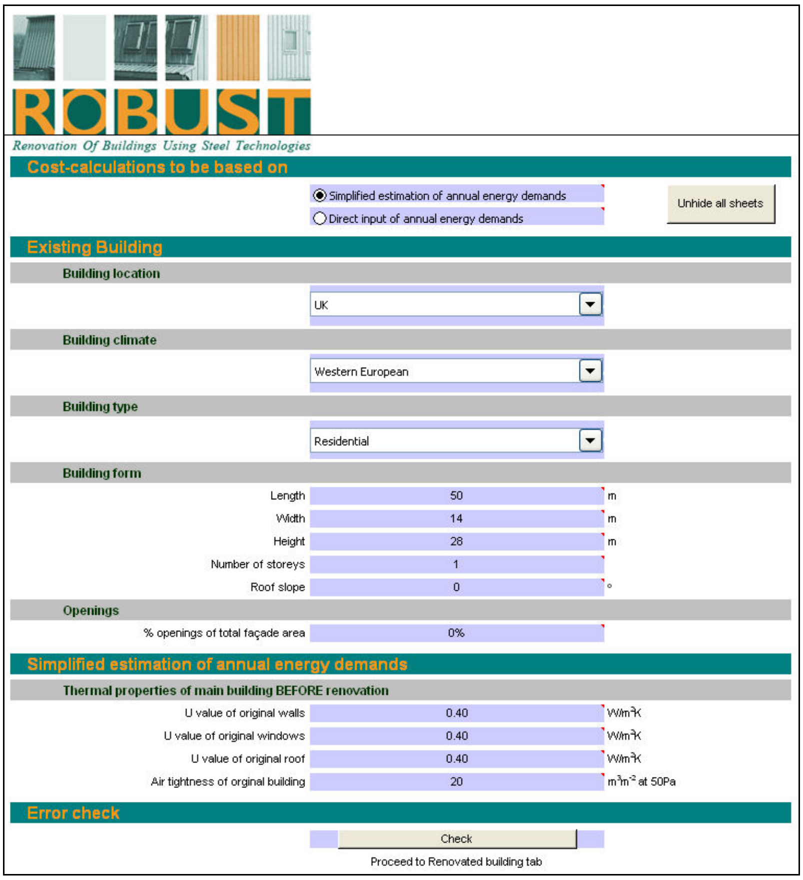


Figure 6.2 *Screenshot of 'Existing building' section of software tool*

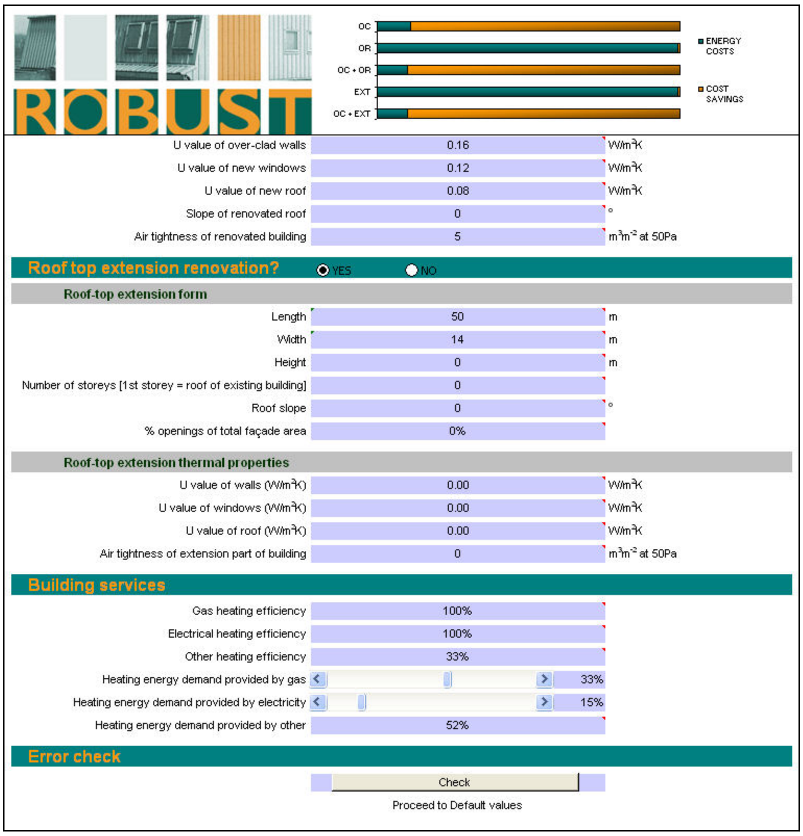


Figure 6.3 *Screenshot of 'Renovated building' section of software tool*

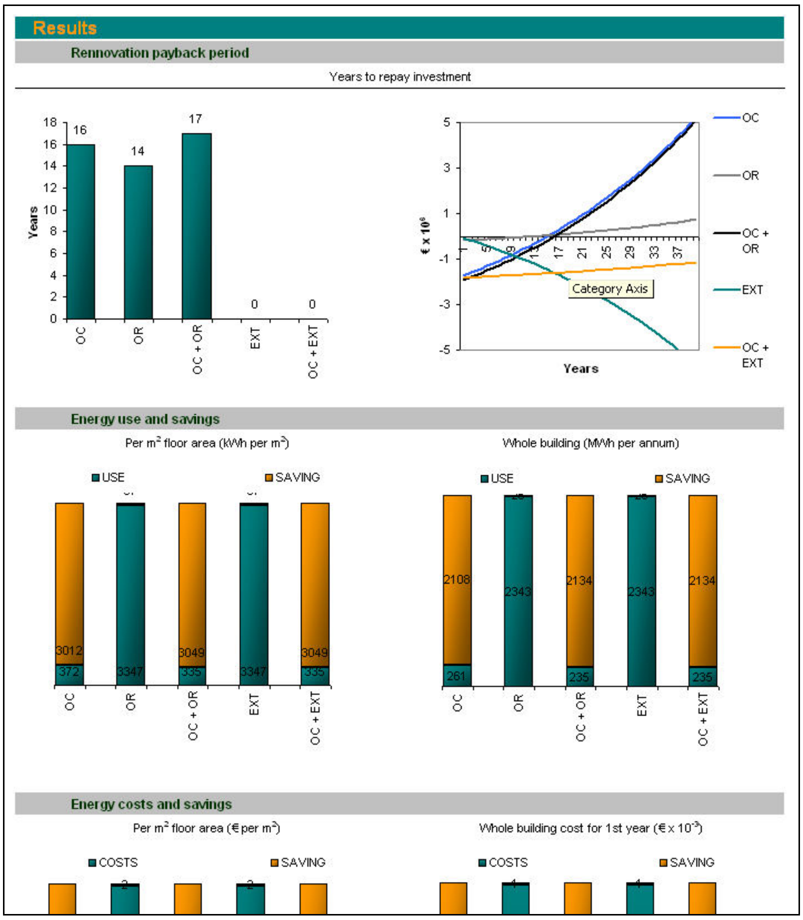


Figure 6.4 *Screenshot of 'Results' section of software tool*

Figure 6.5 *Screenshot of 'Default values' section of software tool*